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(71) Applicants (*for all designated States except US*): **ONESTEEL REINFORCING PTY LTD** [AU/AU]; Level 23, 1 York Street, Sydney, New South Wales 2000 (AU). **UNIVERSITY OF WESTERN SYDNEY** [AU/AU]; Second Avenue, Kingswood, New South Wales 2747 (AU).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): **PATRICK, Mark** [AU/AU]; 32 Lewin Street, Springwood, New South Wales 2777 (AU).

(74) Agent: MUNT, Greg, R.; c/- Griffith Hack, GPO Box 1285K, Melbourne, Victoria 3001 (AU).

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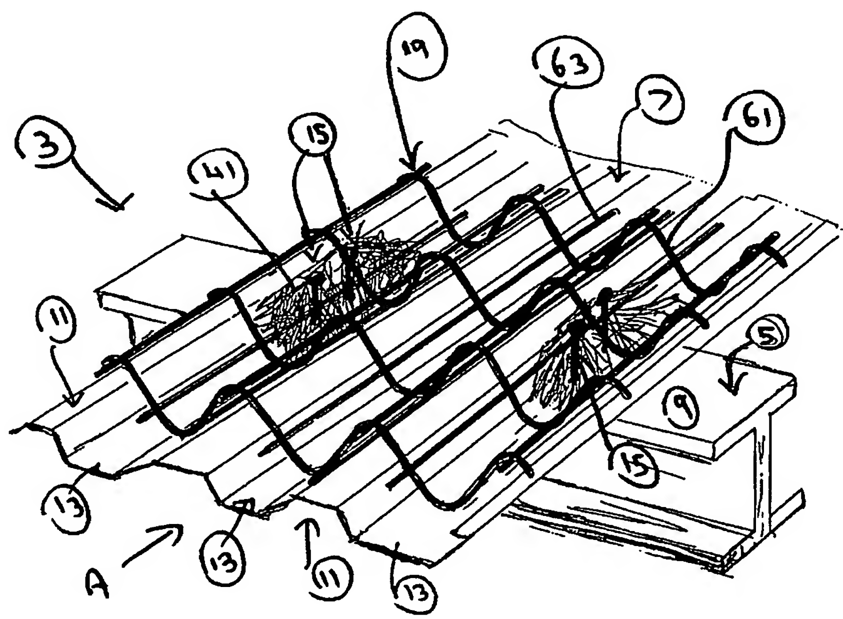
(54) Title: A COMPOSITE BEAM



(57) Abstract: A composite beam is disclosed. The beam includes an internal horizontal beam (5), a composite slab that is positioned on and supported by the beam, and a plurality of shear connectors (15), embedded in the cast concrete and welded to the beam and connecting the composite slab to the beam. The beam is characterised by a reinforcing component (19) that is positioned so that reinforcing elements (61, 63) of the reinforcing component intersect a conical-type failure surface around the shear connectors in at least two different, preferably perpendicular, directions.

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A COMPOSITE BEAM

The present invention relates to composite beams for the construction industry.

The term " composite beam" is understood herein to mean a beam, preferably formed from steel, and a composite slab that are interconnected by the shear connection to act together to resist action effects as a single structural member.

The term " shear connection" is understood herein to mean an interconnection between a beam and a composite slab which enables the two components to act together as a single structural member under the action effect of bending which causes longitudinal shear forces to develop.

In conventional composite beams, typically, the shear connection includes shear connectors, slab concrete, the profiled steel sheeting, and transverse reinforcement.

The term " shear connector" is understood herein to mean a mechanical device attached to a beam (typically to a top flange of the beam) which forms part of the shear connection.

The present invention relates particularly, although by no means exclusively, to composite beams of the type which include:

(a) a horizontal beam (typically steel and supported at each end);

(b) a composite slab that is positioned on and supported by the beam and includes:

(i) profiled metal (typically steel) sheeting having pans and parallel ribs, with the sheeting positioned so that the ribs extend transversely to the longitudinal axis of the beam;

(ii) concrete cast on the sheeting; and

(iii) reinforcement embedded in the cast concrete; and

(c) a plurality of shear connectors, typically in the form of headed studs, embedded in the cast concrete and welded to the steel beam thereby to connect the composite slab to the steel beam.

The term "profiled metal sheeting" is herein understood to include a plurality of sheets of profiled metal deck that have side edge formations that allow the sheets to be positioned in side by side overlapping relationship.

The present invention is concerned with overcoming a major problem identified by the applicant that occurs with composite beams of the type described above, and particularly with the above-described composite beams that include profiled steel decking having open ribs.

The term "open ribs" is understood herein to mean ribs that have a gap of at least 5mm between adjacent sides of the ribs, measured at the mid-height of the ribs.

The problem is a complex type of premature rib pull-off failure mode that has been observed by the applicant in research work on composite beams that include profiled steel decking having open ribs.

The applicant has previously carried out research work in relation to particular edge composite beams and found that the beams failed prematurely by longitudinal shear failure mode involving horizontal splitting between the tops of the ribs of the profiled steel sheeting that were adjacent the pans in which the shear connectors were located. The applicant anticipated that there would be a similar failure mode and profile for the failure surface of other edge composite beams and for internal composite beams.

However, subsequent research work carried out by the applicant has indicated that failure mode and the actual profile of the failure surface of other edge composite beams and for internal composite beams is quite different to that of the particular edge composite beams tested previously and that the reinforcement requirements are different.

Specifically, the applicant has found that the profile of the failure surface of other edge composite beams and for internal composite beams is characterised by tapered or conical surfaces that extend over the shear connectors and down to the pans of the profiled metal sheeting. This failure surface is hereinafter referred to as " the conical-type failure surface" and is illustrated in the drawings and is described further in relation to the drawings.

In relation to edge beams, the applicant has found that as the outstand of the composite slab from the nearest shear connectors increases there is greater

likelihood of premature rib pull-off failure mode. Consequently, there are different reinforcement requirements for edge beams depending on the extent of the slab outstand of the beam.

The applicant has recognised that the premature rib pull-off failure mode needs to be suppressed by a suitable reinforcing component that ties the concrete cone around shear connectors to the more massive portion of the slab around the conical-type failure surface.

With the above in mind, according to the present invention there is provided a composite beam of the general type described above which is characterised by a reinforcing component that is positioned so that reinforcing elements of the reinforcing component intersect the above-described conical-type failure surface in at least two different, preferably perpendicular, directions.

More particularly, the present invention provides a composite beam which includes:

(a) a horizontal beam;

(b) a composite slab that is positioned on and supported by the beam; and

(c) a plurality of shear connectors, typically in the form of headed studs, embedded in the cast concrete and welded to the beam thereby to connect the composite slab to the beam; and

wherein the composite slab includes:

(i) profiled metal sheeting having pans and parallel ribs, with the sheeting

positioned so that the ribs extend transversely to the longitudinal axis of the beam;

(ii) concrete cast on the sheeting; and

(iii) a reinforcing component embedded in the cast concrete, the reinforcing component including a plurality of reinforcing elements, with the reinforcing component being positioned so that the reinforcing elements intersect the above-described conical-type failure surface in at least two different directions.

The applicant has found that the reinforcing component improves dramatically the resistance to the above-described premature rib pull-off failure mode of composite beams, particularly in situations in which the composite beams include profiled steel decking having open ribs.

Relevant factors in the selection of the reinforcing component include the following factors.

- The reinforcing elements of the reinforcing component, e.g. mesh line wires and cross wires, bars, wires, straps, etc. must intersect the conical-type failure surface that forms around the shear connectors in at least two directions, preferably perpendicular directions. In any given situation, it is necessary first to identify the likely location of the conical-type failure surface and then to select the design of the reinforcing component that best suits that

particular failure surface.

- The reinforcing elements at the multiple direction intersection points must be sufficient to tie the concrete within the conical-type failure surface to the portion of the slab outside the conical-type failure surface. This would normally entail positioning reinforcing elements to pass through at least two opposed faces of the conical-type failure surface. Preferably, however, the reinforcing elements pass through two perpendicular pairs of opposed faces of the conical-type failure surface.

Preferably the reinforcing elements extend a sufficient distance on both sides of each intersection point so that the elements are sufficiently well-anchored to develop tensile forces to prevent shear failure around the conical-type failure surface, noting that such tensile forces create a clamping force across the failure surface which causes friction to develop which resists shear failure around the surface.

Preferably the reinforcing elements extend a sufficient distance on both sides of each intersection point so that a similar failure surface cannot occur further away from the shear connectors, which would also lead to a concrete pull-out failure, albeit at a higher level of shear force.

Preferably the reinforcing elements are connected together to form a single unit to simplify installation during construction. Depending on the design of the component, the connections between the reinforcing elements may be strong (e.g. welded-wire mesh) or weak (e.g. bars tack-welded or wire-tied together).

Preferably the reinforcing component does not clash with other reinforcement required in the composite slab.

Preferably there is sufficient concrete cover to the top of the slab for durability, etc.

Preferably the reinforcing component includes line wires and cross wires connected together at the intersections of the wires, for example by welding and/or wire-tying, with the line wires and the cross wires forming the reinforcing elements, and with the reinforcing component being positioned so that there are line wires and cross wires that have multiple points of intersection with the above-described conical-type failure surface around each shear connector or group of shear connectors.

Preferably the reinforcing component is in the form of a mesh that includes line wires and cross wires that are connected together, for example by welding and/or wire-tying, at the intersections of the wires, with the line wires and the cross wires forming the reinforcing elements.

In one, although not the only, arrangement the reinforcing component is in the form of a mesh formed from line wires and cross wires that are connected together, for example by welding and/or wire-tying, at wire intersections, with the line wires and the cross wires forming the reinforcing elements, and with the line wires having a zig-zag or "waveform" shape with peaks and troughs along at least part of the length of the line wires. With this arrangement, preferably the mesh is positioned in relation to the ribs and pans of the profiled metal sheeting so that the cross wires are parallel to the ribs and are positioned in the pans and extend through the conical-type failure surface or surfaces, the peaks of the

waveform line wires are positioned above the ribs (preferably 30-40mm), the troughs of the waveform line wires are positioned in the pans, and sections of the waveform line wires between the peaks and the troughs extend through the conical-type failure surface or surfaces.

The applicant has found that in the above arrangement the cross wires are very important in terms of reinforcing the composite beam at the conical-type failure surface.

Types of the reinforcing component other than mesh include, by way of example, reinforcing bars or wire, steel strapping (possibly holed), light steel sections, and high-strength plastics.

One particular design of the reinforcing component is in the form of a bar chair designed to be positioned to protrude through the conical-type failure surface at multiple points.

It is preferred that the reinforcing component be positioned so that a substantial part of the transverse reinforcement of the component is located between 10% and 75% of the height of adjacent ribs.

It is preferred that the beam be a steel beam.

It is preferred that the profiled metal sheeting be profiled steel sheeting.

The ribs of the profiled metal sheeting may be open or closed ribs. The present invention is applicable particularly to profiled metal sheeting having open ribs because composite slabs with open ribbed profiled metal

sheeting are more susceptible to the premature rib pull-off failure mode described above.

The beam may be supported at opposite ends and at one or more locations along the length of the beam.

It is preferred that the shear connectors be headed studs.

The shear connectors may be of any other suitable form such as a structural bolts or channels or shot-fired connectors.

According to the present invention there is also provided a reinforcing component for the above described internal composite beam.

The present invention is described further by way of example with reference to the accompanying drawings of which:

Figure 1 is a perspective view which illustrates, in simplified form, an embodiment of a composite beam (without a layer of concrete that forms part of the beam) in accordance with the present invention which illustrates the location of the reinforcing component of the beam in relation to the shear connectors of the beam and which also illustrates the location of the conical-type failure surface that the reinforcing component reinforces in the beam;

Figure 2 is an elevation of the composite beam shown in Figure 1 (with the layer of concrete illustrated in the Figure) in the direction of the arrow A in Figure 1;

Figure 3 is a perspective view of the reinforcing component of the embodiment of the composite beam in

accordance with the present invention that is shown in Figure 1.

The preferred embodiment of the composite beam 3 in accordance with the present invention that is shown in the Figures is in a simplified form to illustrate the composite beam 3 more clearly. It is noted that the composite beam may be an edge beam or an internal beam.

With reference to the Figures, the composite beam 3 includes:

(a) a horizontally extending hot-rolled or fabricated steel beam 5 which is supported at each end, and optionally at least one location along the length of the beam so that the beam extends across multiple spans between the beam supports;

(b) a composite slab including:

  (i) profiled steel sheeting 7 in contact with a top flange 9 of the steel beam 5, the sheeting 7 including a plurality of parallel steel open ribs 11 separated by pans 13 and positioned so that the ribs 11 extend in a direction that is transverse (in the illustrated embodiment - perpendicular) to the longitudinal axis of the beam 5; and

  (ii) a layer 29 of concrete cast on the sheeting 7 and having an upper surface 31 (shown in Figure 2 only);

(c) two pairs of shear connectors 15 in the form of headed studs that extend through the sheeting 7 and are welded to the top flange 9 of the beam 5

at spaced intervals along the length of the beam 5; and

(d) a reinforcing component generally identified by the numeral 19 embedded in the concrete slab for preventing premature rib pull-off failure mode of the composite beam 3.

The beam 5 and the composite slab may be of any suitable dimensions and construction. Typically, the composite slab has a thickness of at least the height of the ribs 11 and 50mmmm, typically 50-100mm, above the rib height.

In addition, whilst the sheeting 7 shown in the Figures has open ribs, the ribs may be closed ribs.

As is indicated above, the purpose of the reinforcing component 19 is to intersect in at least 2 directions the conical-type failure surface that forms around the shear connectors. As is described hereinafter, in the described embodiment, the reinforcing component 19 intersects the conical-type failure surface in two perpendicular directions.

In any given situation, it is necessary first to identify the likely location of the conical-type failure surface and then to design the reinforcing component accordingly.

In addition, in any given situation, there must be reinforcement at the intersection points that is sufficient to tie the concrete within the conical-type failure surface to the portion of the slab above the conical-type failure surface. This would normally entail positioning reinforcing elements through at least two opposed faces of the conical-type failure surface. However,

preferably the reinforcing elements of a reinforcing component pass through two pairs of opposed faces of the conical-type failure surface.

Figures 1 and 2 illustrate in diagrammatic form the shape of a conical-type failure surface that the applicant found in push-off tests. Specifically, the Figures illustrate the concrete that remained around the shear connectors 15 after the tests. The surface of the remaining concrete, which is the conical-type failure surface, is identified by the numeral 41 in Figures 1 and 2.

The reinforcing component 19 shown in the Figures comprises a sheet of mesh having four parallel line wires 61 and ten parallel cross wires 63 that are welded together at the intersections of the wires and the line wires 61 are formed into a generally sinusoidal waveform with peaks and troughs along the length of the line wires 61. The line wires 61 and the cross wires 63 form reinforcing elements of the reinforcing component 19.

Typically, the line wires 61 and the cross wires 63 are formed from plain or deformed wire having a diameter of 6-8 mm. The main requirement for the line wires 61 and the cross wires 63 is that they be capable of acting as reinforcement. Typically, there is a spacing of 150 mm between the line wires 61 - thus making 450 mm the nominal width of the reinforcing component 19.

The reinforcing component 19 is formed with regard to the height of the ribs 11 and the height of the shear connectors 15 and the location of the conical-type failure surfaces 41 shown in the Figures so that when the reinforcing component 19 is positioned as shown in Figures 1 and 2 the longitudinal wires 61 and the lower cross-wires 63 intersect the conical-type failure surfaces 41 at

multiple locations in two perpendicular directions. In the arrangement shown, the reinforcing component 19 is positioned so that the cross wires 63 are parallel to the ribs 11 and the peaks of the longitudinal wires 61 extend over the ribs 11 (with 30-40mm clearance) and the troughs of the longitudinal wires 61 extend into the pans 13. Furthermore, in the arrangement shown, the cross wires 63 that are in the pans 13 that have the pairs of shear connectors 15 are positioned approximately half way up the height of the ribs 11. The applicant has found that positioning the reinforcing component 19 so that the cross wires 63 are between 10 and 75%, more preferably between 25 and 75%, of the height of the ribs 11 provides particularly effective reinforcement.

When a structural composite beam 3 of the basic type shown in the Figures is loaded, longitudinal slip is induced between the composite slab and the steel beam 5 which is resisted by the shear connection between these components.

In a conventional structural composite beam (without the reinforcing component 19) the shear connection includes:

(a) the shear connectors 15;

(b) concrete cast in a slab;

(c) profiled steel sheeting 7; and

(d) conventional horizontal reinforcement (not shown) in the vicinity of the shear connectors 15 and at the level of the top of the sheeting ribs.

However, in accordance with the present

invention, the shear connection also includes the reinforcing component 19.

Many modifications may be made to the preferred embodiment of the present invention described above without departing from the spirit and scope of the invention.

Claims:

1. A composite beam which includes:

(a) a horizontal beam;

(b) a composite slab that is positioned on and supported by the beam; and

(c) a plurality of shear connectors, typically in the form of headed studs, embedded in the cast concrete and welded to the beam thereby to connect the composite slab to the beam; and

wherein the composite slab includes:

(i) profiled metal sheeting having pans and parallel ribs, with the sheeting positioned so that the ribs extend transversely to the longitudinal axis of the beam;

(ii) concrete cast on the sheeting; and

(iii) a reinforcing component embedded in the cast concrete, the reinforcing component including a plurality of reinforcing elements, with the reinforcing component being positioned so that the reinforcing elements intersect the conical-type failure surface or surfaces as described herein in at least two different directions.

2. The beam defined in claim 1 wherein the reinforcing elements extend a sufficient distance on both sides of each intersection point so that the elements are sufficiently well-anchored to develop tensile forces to prevent shear failure around the conical-type failure surface or surfaces.

3. The beam defined in claim 1 or claim 2 wherein the reinforcing elements extend a sufficient distance on both sides of each intersection point so that a similar failure surface cannot occur further away from the shear connectors.

4. The beam defined in any one of the preceding claims wherein the reinforcing component includes line wires and cross wires connected together at the intersections of the wires, with the line wires and the cross wires forming the reinforcing elements, and with the reinforcing component being positioned so that there are line wires and cross wires that have multiple points of intersection with the conical-type failure surface around each shear connector or groups of shear connectors in a pan.

5. The beam defined in any one of the preceding claims wherein the reinforcing component is in the form of a mesh that includes line wires and cross wires that are connected together at the intersections of the wires, with the line wires and the cross wires forming the reinforcing elements.

6. The beam defined in claim 4 or claim 5 wherein the reinforcing component is in the form of a mesh formed from line wires and cross wires that are connected together at wire intersections, with the line wires and the cross wires forming the reinforcing elements, with the line wires

having a zig-zag or " waveform" shape with peaks and troughs along at least part of the length of the line wires, and with the mesh positioned in relation to the ribs and pans of the profiled metal sheeting so that the cross wires are parallel to the ribs and are positioned in the pans and extend through the conical-type failure surface or surfaces, the peaks of the waveform line wires are positioned above the ribs, the troughs of the waveform line wires are positioned in the pans, and sections of the waveform line wires between the peaks and the troughs extend through the conical-type failure surface or surfaces.

7. The beam defined in any one of claims 1 to 3 wherein the reinforcing component is in the form of a bar chair designed to be positioned to protrude through the conical-type failure surface at multiple points.

8. The beam defined in any one of the preceding claims wherein the reinforcing component is positioned so that a substantial part of the transverse reinforcement is located between 10% and 75% of the height of the adjacent ribs.

9. The beam defined in any one of the preceding claims wherein the ribs are open ribs.

Figure 2

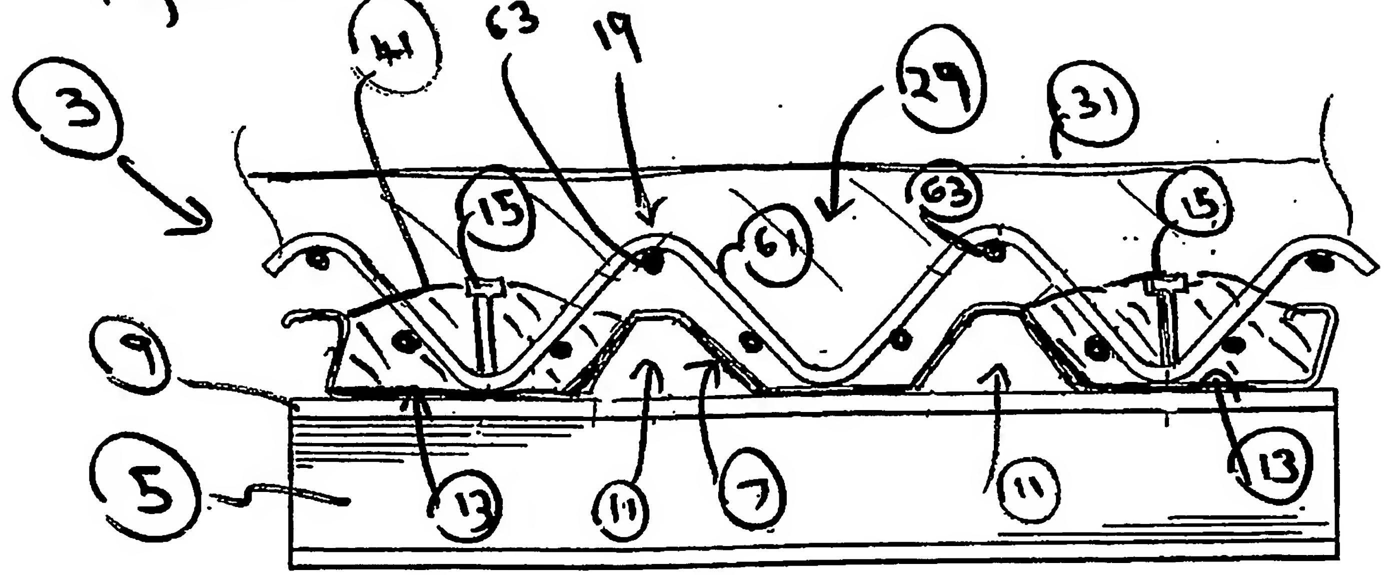

Figure 1

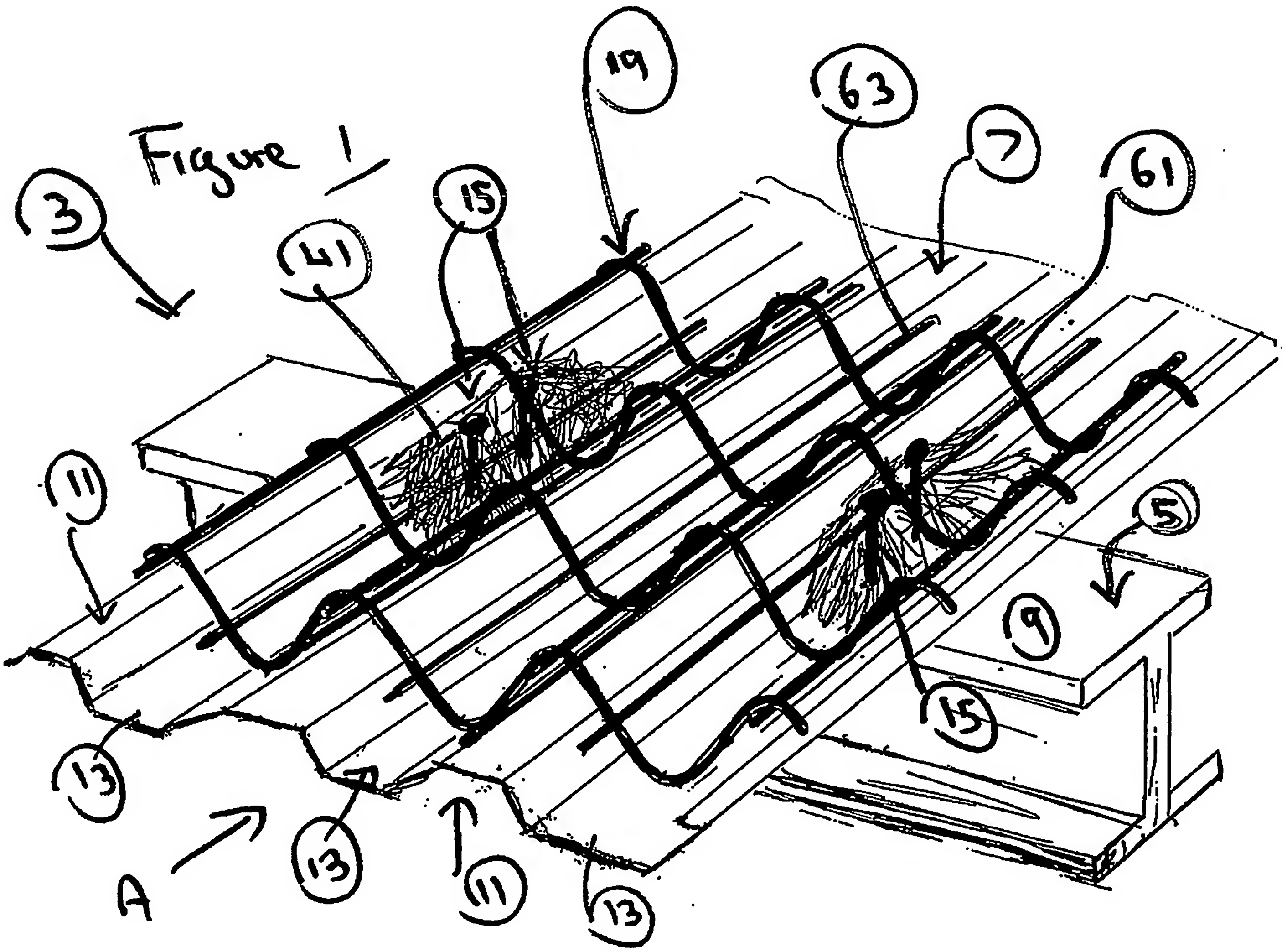

Figure 3